

RAW MATERIALS

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MAGNETIC SEPARATION OF RAW MATERIALS FOR GLASS AND CERAMIC PRODUCTION: PROBLEMS OF FERRUGINOUS IMPURITY CONTROL (REVIEW)

A. V. Sandulyak,^{1,2} A. A. Sandulyak,¹ D. V. Ershov,¹ D. A. Sandulyak,¹ and V. A. Ershova¹

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A large mass of data on magnetic separation of raw materials for the production of glass and ceramic is generalized using a key indicator — the separation efficiency (relative decrease of the ferruginous impurity content); the unsystematic variation of the data is determined. It is established that the results of conventional control (in terms of a “single” form of impurity Fe_2O_3), though providing a basis for judging the presence of a formal concentration dependence, nonetheless do not permit logical systematization of the accumulated mass of data by evaluating media with respect to their “proneness” to separation and evaluation of separators according to their address preference. The method of magnetic control is recommended for purposeful control of impurities which are active in a separator.

Key words: separation efficiency, concentration dependence, magnetoactive impurities, magnetic control.

A key quality parameter for the raw materials (quartz sand, feldspar, quartz, chalk, talc, and so on) used for manufacture of glass and ceramic articles is the presence of ferruginous impurities (impurities based on iron, whose content is usually given in terms of the oxide Fe_2O_3) in them. For example, the normal content of such impurities in quartz sand and vein quartz ranges from $\leq 0.01\%$ for manufacture of optical glass, lead crystal, artistic and other essential articles to $0.1 - 0.25\%$ for manufacture of window glass, insulators, tubes, food containers and bottles made of semiwhite glass (to make the content of Fe_2O_3 in white bottle glass close to the European standard, specifically, $\leq 0.045\%$, the quality requirements for raw materials must be made more stringent [3]), glass fibers for building purposes and other articles [1]. For quartz feldspar materials (for manufacture of sanitary-ceramic articles, finishing and facing tiles and low-temperature porcelain) this standard is $0.2 - 0.3\%$ [2].

The actual values of the content of these impurities in the most diverse forms of raw materials, as a rule, exceed their norms (often considerably). This makes it necessary to intensify the process line for preparing raw materials by using

methods and facilities that reduce the content of these impurities in the raw material, among which, undoubtedly, the method of magnetic separation, which is implemented in many designs of magnetic separators, is widely used.

A great deal of experience in operating different separators, as reflected in numerous scientific and scientific-applied works [3 – 19], has been accumulated. Of course, to develop a method of magnetic separation of raw materials and purposefully expand the sphere of application of magnetic separators this experience must be appropriately generalized. This would make it possible to “grade” media, separators (from the standpoint of separation effectiveness) and specific applications of separators and to identify objectively innovative (excluding patently promotional) and “disastrous” engineering-technological solutions.

An attempt at such a generalization is presented in the form of a table which contains data for sand [4 – 12], feldspar [4, 10, 13], quartz [13], chalk [13, 14] and grit from ceramic scrap [15]. Not only conventional information on the origin (or user) of a raw material, type of separator, and Fe_2O_3 impurity content in the material before and after separation were taken into account. Thus, a fundamental (in our opinion and generally acknowledged in allied fields of implementation of magnetic separation: ore and coal enrich-

¹ Moscow State Civil Engineering University, Moscow, Russia.

² E-mail: a.sandulyak@mail.ru.

ment, power generation, metallurgy, chemical technology and elsewhere) indicator — the separation efficiency ψ — was drawn into arguments meriting special attention (see Table 1). The separation efficiency is the relative difference of the input c_0 and output c mass fractions of the impurities (see Table 1); it is calculated from the expression $\psi = (c_0 - c)/c_0 \times 100\%$.

Of course, to generalize the data presented in Table 1 it would be very desirable to have in addition detailed information about the design and regime parameters of separators. Unfortunately, however, it is virtually always absent or is clearly incomplete. Thus, instead of a detailed topography of the field in the working zone, using which it would be possible to judge the remotely changed character of the gradient and force factor, often only the point (near a pole) value of the intensity or induction is given to advantage. And, sometimes, the gradient and force factor values which appear are represented by constants, thereby contradicting the very meaning of the field distribution in the working zone.

Analysis of real data presented in Table 1 shows that, unfortunately, it is difficult to obtain such desirable results from generalization (first and foremost, the conceptual information mentioned). The possibility of logical systematization of the data, which this requires, is unavailable because of their inconsistency and large unsystematic variance. This is illustrated not only by the data in Table 1 but also more graphically by the same data displayed graphically in Fig. 1. The coordinates-parameters can be the naturally “given” input concentration c_0 of the ferruginous impurities (according to the data presented in Table 1, for different media it was fixed in a quite wide range — within two orders of magnitude) and the computed value of the separation efficiency ψ . Incidentally, there is a definite correlation between c_0 and ψ (see Fig. 1, dashed line).

In regard to the factors impeding logical systematization of the mass of data presented in Table 1 and Fig. 1 (seemingly sufficient for this), one such factor is, undoubtedly, the almost always biased attitude to controlling ferruginous impurities, which reduces to obtaining “results” for Fe_2O_3 by photographic [20, 21] and other methods involving treatment of a sample with reagents.

Strictly speaking, when these control methods are implemented the oxide Fe_2O_3 is not measured strictly, as one may think at first glance. Thus, preliminary chemical treatment of the sample being analyzed (decomposition in acid or by melting with alkali) [20, 21] converts the iron present in the form of “independent” particles as well as in the most diverse compounds-particles (including, of course, Fe_2O_3) into the ionic form. And, a calibration curve specially obtained for preparing standard solutions of precisely iron (III) oxide, using for this iron-ammonium alums, desiccated iron oxide, and carbonyl iron (subjecting them to the appropriate chemical treatment), is used only to subsequently find the mass fraction of the dissolved component (starting from the measured values of the optical density of the solution) [20, 21].

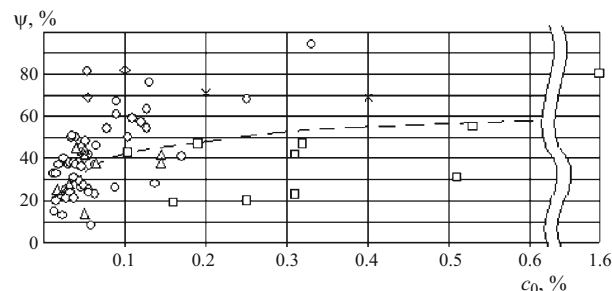


Fig. 1. Operational data (see Table 1) in the form of the mass content field c_0 of ferruginous impurities in the raw material and the values of the efficiency ψ of its magnetic separation: (○) sand; (□) feldspar; (△) quartz; (◇) chalk; (×) grit from ceramic scrap.

The formal (and somewhat misleading) opinion that there is only one form for ferruginous impurities — Fe_2O_3 — follows from here. The information on iron “being” one or another actual ferruginous inclusion is lost completely.

It is well known that ferruginous impurities in the raw materials used for the manufacture of glass and ceramic are present (according to many studies performed using chemical methods, x-ray structural analysis, Mössbauer and electron-paramagnetic spectroscopy, and magnetic and thermomagnetic methods) in the most diverse forms [3, 5, 8, 15, 22 – 24]. Specifically, these are iron Fe in the multidomain crystalline form (for example, particles from wearing of steel equipment), iron Fe in ionic form and, of course, all-possible iron compounds, including $\alpha\text{-Fe}_2\text{O}_3$, $\gamma\text{-Fe}_2\text{O}_3$, Fe_3O_4 , FeO , $\alpha\text{-FeOOH}$, FeCO_3 , FeS_2 and others [3, 5, 8, 15, 22 – 24].

Of course, the fraction of the oxide Fe_2O_3 in all ferruginous impurities is different not only for the same form of raw material taken from different deposits but also for raw materials taken from the same deposit, to say nothing of different forms of raw material. As an example, estimates show that the iron oxide fraction in the balance of all Fe compounds (in terms of Fe_2O_3) ranges from 0.1 – 0.2 for aluminum-containing raw materials (excluding alumina) and dolomite to 0.7 for quartz sand [3]. In [23] it is estimated that ferruginous impurities present in clays contain mainly trivalent iron (with bivalent iron fraction to 0.1), and since trivalent iron is present in the commonly occurring oxide Fe_2O_3 it can be assumed that the representation of this oxide in clays is substantial.

However, from the standpoint of potential applications and operational efficiency of magnetic separators, which remove, first and foremost, precisely the magnetically active inclusions-impurities, information (almost always absent) on the content of impurities possessing ferro- and ferrimagnetic properties (ferro- impurities) and not formal information on the content of a quasi-ideal form of ferruginous impurities in the form of iron Fe_2O_3 must still be of central importance. In this connection it is not superfluous to note that even iron oxide itself is not unique in regards to such properties: in he-

TABLE 1. Systematized Data on the Magnetic Separation of Raw Materials Used in the Manufacture of Glass and Ceramic Articles

Raw material	Mining-enrichment combine, quarry, deposit, user enterprise	Separator*	Fe ₂ O ₃ content, %		Efficiency, %
			before	after	
Sand [4]	Novoselovskii	SMRS 12/20-A	0.015	0.012	20
	Stzhelech-Ėksimos	SMRS 12-19/120-AR	0.012	0.008	33
	Novoselovskii	SMRS 12/20-ARR	0.015	0.010	33
	Byala Gura	SMRS 12/20-A	0.013	0.011	15
	Novoselovskii	The same	0.019	0.012	37
	Papernyanskii	" "	0.024	0.021	13
	Byala Gura	" "	0.023	0.018	22
	Novoselovskii	SMRS 19/50-A	0.025	0.015	40
	The same	SMRS 12/20-A	0.030	0.019	37
	Ramenskii	SMRS 12/20-AR	0.031	0.024	23
	Sobutka	SMRS 12/120-RR	0.032	0.020	38
	Spasskii	SMRS 12/20-A	0.052	0.030	42
	Aral'skii	SMRS 19/120-A	0.055	0.041	25
	The same	The same	0.046	0.034	26
	Vol'nogorskii	SMRS 12/120-AR-023	0.052	0.030	42
	Polozhskii	SMRS 12/20-AR	0.078	0.036	54
	Voronezh Mining Group	SMRS 12-19/120-AR	0.089	0.035	61
	The same	The same	0.089	0.029	67
	Kara-Sorskii	SMRS 19/50-A	0.103	0.052	50
	Strelitskii	SMRS 12/20-A	0.130	0.031	76
	Tolmachevskii	SMRS 12/20-AR	0.109	0.045	59
	Tashlinskoe	The same	0.040	0.020	50
	Interglass	SMRS 19/120-A	0.088	0.065	26
	Glass Company SAF	SMRS 12/120-RR	0.064	0.049	23
	Vol'nogorskii Glass Plant	SMRS 12/120-AR	0.052	0.030	42
	Kamyshin Glass Works	The same	0.137	0.099	28
Sand [5]	Novoselovskii	LMO 10000	0.037	0.023	38
	Oleshnya	The same	0.038	0.026	31
	Avdeevka	" "	0.055	0.042	24
Sand [6]	Vol'nogorskii Mining-Metallurgical Complex	S+R	0.055	0.032	42
	The same	The same	0.052	0.027	48
	Strong	R	0.33	0.02	94
Sand [7]	—	—	0.045	0.032	29
	—	—	0.17	0.1	41
Sand [8]	Bogdanovskoe	—	0.059	0.054	8
	The same	SÉM-1	0.063	0.040	37
	" "	The same	0.049	0.036	27
	" "	" "	0.028	0.021	25
	" "	" "	0.028	0.022	21
	" "	" "	0.023	0.020	13
Sand [9]	Ramenskoe	2ÉVS 36/100	0.040	0.025	37
	The same	The same	0.038	0.030	21
	" "	" "	0.033	0.025	24
	" "	LMO 10000	0.033	0.025	24
	" "	The same	0.038	0.030	21

Table continuation

Raw material	Mining-enrichment combine, quarry, deposit, user enterprise	Separator*	Fe ₂ O ₃ content, %		Efficiency, %
			before	after	
Sand [10]	Muraevnya	SMVI	0.065	0.035	46
	Ramenskii	The same	0.034	0.017	50
	Balakhninskoe	" "	0.12	0.051	57
	Tashlinskoe	" "	0.054	0.01	81
Sand [11]	Ushinskoe	MBSOU-164/200	0.25	0.08	68
	The same	The same	0.047	0.03	36
	" "	SMBI	0.127	0.047	63
	" "	The same	0.047	0.026	45
	" "	SMRS	0.127	0.058	54
	" "	The same	0.047	0.027	43
Sand [12]	Tashlinskii	—	0.035	0.017	51
Feldspar [4]	Chupinskii	SMRS 12/20-AR	0.19	0.10	47
	Petrovskii	The same	0.25	0.20	20
	Gornyi	" "	0.31	0.24	23
	Vyshnevogorskii	" "	0.31	0.18	42
	Sobutka	" "	0.32	0.17	47
	Rudnik	" "	0.51	0.35	31
	Chupinskii	" "	0.53	0.24	55
	Berdyanskii	" "	1.6	0.3	81
Feldspar [10]	Malyshevskii	SMVI	0.103	0.059	43
Feldspar [13]	Svet	ASMK	0.160	0.130	19
Quartz [13]	Muraevnya	SMBM + SMVI	0.065	0.040	38
	The same	The same	0.040	0.022	45
	" "	" "	0.016	0.012	25
	" "	" "	0.050	0.028	44
	" "	SMBM	0.050	0.043	14
	" "	SMB + SMVI	0.050	0.029	42
	Quartzit	SMBM + SMVI	0.144	0.084	42
	The same	ASMK + SMVI	0.144	0.090	38
	Svet	SMVI	0.032	0.023	28
	Akron	SMVI	0.100	0.018	82
Chalk [13]	The same	The same	0.054	0.017	69
Chalk [14]	Akron	B	0.05	0.03	40
Grit from ceramic	Shcherbinska Refractories Plant	UMO-2B-K	0.4	0.122	69
scrap [15]	The same	The same	0.2	0.058	71

* In the absence of a serial number the type is indicated: B) drum; R) roller S) rod.

matite α -Fe₂O₃ they are substantially attenuated compared with maghemite γ -Fe₂O₃ [25].

The absence of this extremely necessary information, specifically, information about the content of magnetically active impurities (the content and composition of these impurities, just as the entire spectrum of ferruginous impurities, are specific to each individual case) engenders unpredictability — incompatibility of the results of operating magnetic separators. Hence follows the impossibility of logical sys-

tematization of such incomplete and therefore contradictory (see Table 1 and Fig. 1) results obtained with separators (of course, the absence or incompleteness of other information, specifically, about structural and regime parameters of separators also promotes this, but these questions are less important and a subject for a separate discussion).

Therefore, the question of controlling magnetically active impurities, which are always present in different forms of the raw materials used to manufacture glass and ceramic

articles, as a key question in solving the problems of magnetic separation of one or another raw material is very topical and merits special attention.

In this regard the approach based on the method of magnetic control, which, it must be said, is envisaged for a number of media in the construction industry, is useful [26 – 29]. In contrast to the conventional methods, specifically, photo-colorimetric [24, 25], it makes possible purposeful solution (taking account of additional development work required for reliable implementation [30 – 33]) of the magnetic separation problem.

REFERENCES

1. GOST 22551–77. *Quartz Sand, Ground Sandstone, Quartzite and Vein Quartz for the Glass Industry: Technical Conditions (update March 22, 2010)* [in Russian], Moscow (1977).
2. GOST 15045–78. *Quartz-Feldspar Materials for Building Ceramic: Technical Conditions (update March 22, 2010)* [in Russian], Moscow (1978).
3. P. P. Tkachev and I. D. Khait, "Raw materials, optimization of commercial batch and glass ($\text{SiO}_2\text{--R}_2\text{O}_3\text{--RO--R}_2\text{O}$) compositions to decrease production costs and improve product quality. Some problems of quality control," in: *Reports at the 9th International Seminar on the Application of Magnetic Separators in Industry* [in Russian], Rovno (2005), pp. 11 – 17.
4. R. T. Artyushov, "Application and construction of a roller separator based on Nd–Fe–B magnets for separating quartz sand, feldspar and other loose materials," *Ibid.*, pp. 28 – 32.
5. N. N. Konev, I. P. Salo, N. F. Mel'nik, and V. N. Gordiichuk, "Magnetic additional enrichment of quartz sand in glass plants," *Steklo Keram.*, No. 5, 33 – 34 (2003).
6. A. A. Lozin, "On the problem of enrichment of quartz sands," in: *Reports at the 9th International Seminar on the Application of Magnetic Separators in Industry* [in Russian], Rovno (2005), pp. 3 – 4.
7. A. A. Karnaukhov, "Problems of and prospects for dry enrichment of quartz sands," *Ibid.*, pp. 5 – 9.
8. A. D. Savko and V. P. Mikhin, "Glass sands in Aptian deposits in the Don-Veduga interfluvium," *Vestn. Voronezh. Univer. Geologiya*, No. 1, 152 – 166 (2005).
9. N. N. Konev, I. P. Salo, Yu. P. Lezhnev and V. P. El'skii, "Magnetic enrichment of quartz sand for the glass industry," *Steklo Keram.*, No. 2, 21 – 22 (2001); N. N. Konev, I. P. Salo, Yu. P. Lezhnev and V. P. El'skii, "Magnetic concentration of quartz sand for glass industry," *Glass Ceram.*, **58**(1 – 2), 57 – 59 (2001).
10. S. V. Kotunov and A. V. Vlasko, "Experience in enriching non-metallic materials using separators based on rare-earth permanent magnets," *Steklo Keram.*, No. 5, 22 – 23 (2007); S. V. Kotunov and A. V. Vlasko, "Experience in using separators based on rare-earth permanent magnets to enrich nonmetalliferous materials," *Glass Ceram.*, **64**(5 – 6), 169 – 170 (2001).
11. E. B. Zolotykh, I. A. Mamina, and O. V. Paryushkina, "Extraction of magnetic minerals from glass sands of the Ushinskoe deposit," *Stroit. Mater.*, No. 5, 22 – 24 (2007).
12. O. V. Paryushkina, O. E. Khario, A. V. Yashchenko, et al., "Technical re-equipping of Kvartz, JSC (Tashinskii Mining-Enrichment Combine) in Ul'yanovsk Oblast," *Stroit. Mater. Oborud. Tekhnol. XXI Veka*, No. 12, 18 – 19 (2005).
13. E. A. Zemlyacheva, S. V. Kotunov, and A. V. Vlasko, "Magnetic enrichment of raw materials – new technologies," *Steklo Keram.*, No. 5, 34 – 35 (2006).
14. N. N. Konev and I. P. Salo, "Magnetic separators with permanent magnets for enrichment of raw materials and materials for glass and ceramic production," *Steklo Keram.*, No. 2, 30 – 31 (2000).
15. E. V. Bychkov, V. D. Filatov, S. N. Knyazev, et al., "Use of magnetic separation in the production of electro-melted refractories," *Steklo Keram.*, No. 9, 42 – 43 (2000); E. V. Bychkov, V. D. Filatov, S. N. Knyazev, et al., "Use of magnetic separation in the production of electro-melted refractories," *Glass Ceram.*, **57**(9 – 10), 328 – 329 (2000).
16. N. N. Konev and I. P. Salo, "Removal of ferruginous impurities by magnetic separation," *Steklo Keram.*, No. 1, 28 – 29 (1999); N. N. Konev and I. P. Salo, "Removal of iron-containing impurities using the magnetic separation method," *Glass Ceram.*, **56**(1 – 2), 32 – 33 (1999).
17. O. A. Dolgoplov, "New-generation magnetic roller separators with permanent magnets for enrichment and purification of weakly magnetic materials," *Steklo Keram.*, No. 5, 33 (2005); O. A. Dolgoplov, "A new generation of magnetic roll separators based in rare-earth magnets for concentration and purification of weakly magnetic materials," *Glass Ceram.*, **62**(5 – 6), 155 – 156 (2005).
18. E. A. Zemlyacheva and S. V. Kotunov, "New-generation magnetic separators for the glass and ceramics industry," *Steklo Keram.*, No. 5, 35 – 36 (2003).
19. N. N. Konev, "Magnetic enrichment of quartz sands. Analysis of separator operation," *Steklo Keram.*, No. 5, 12 – 17 (2010); N. N. Konev, "Magnetic enrichment of quartz sands. Analysis of separator operation," *Glass Ceram.*, **67**(5 – 6), 12 – 17 (2010).
20. GOST 22552.2–93. *Quartz Sand, Ground Sandstone, Quartzite and Vein Quartz for the Glass Industry. Methods of Iron Oxide Determination (update March 22, 2010)* [in Russian], Moscow (1993).
21. GOST 26318.3–84. *Nonmetallic Materials. Methods for Determination of the Iron (III) Oxide Mass Fraction (update March 22, 2010)* [in Russian], Moscow (1984).
22. G. N. Maslennikova, R. A. Khalilylova, and Yu. T. Platov, "Identification of iron compounds in clayey materials," *Steklo Keram.*, No. 2, 12 – 15 (1999); G. N. Maslennikova, R. A. Khalilylova, and Yu. T. Platov, "Identification of iron compounds in clay-containing materials," *Glass Ceram.*, **56**(1 – 2), 48 – 51 (1999).
23. B. K. Kara-sal, "Effect of iron compounds on sintering of clayey pastes at low pressure of the sintering medium," *Steklo Keram.*, No. 2, 13 – 16 (2005); B. K. Kara-sal, "The effect of ferrous compounds on sintering of clay mixtures under decreased pressure of firing medium," *Glass Ceram.*, **62**(1 – 2), 45 – 48 (2005).
24. Z. A. Avakyan, Yu. T. Platov, R. A. Khalilylova, et al., *Method of Whitening Clayey Ceramic Raw Material, Patent RF No. 2083527* [in Russian], Moscow (1997).
25. V. V. Karmazin and V. I. Karmazin, *Magnetic and Electric Methods of Enrichment* [in Russian], Nedra, Moscow (1988).
26. GOST 23789–79. *Binding Gypsums. Methods of Testing. Determination of Metal Impurities Content in Binder (update March 22, 2010)* [in Russian], Moscow (1979).
27. GOST 25216–82. *Talc and Talc-Magnesite. Method of Determining Iron (update March 22, 2010)* [in Russian], Moscow (1982).

28. GOST 8253–79. *Chemically Precipitated Chalk. Technical Conditions (update March 22, 2010)* [in Russian], Moscow (1979).
29. GOST 23672–79. *Dolomite for the Glass Industry. Technical Conditions (update March 22, 2010)* [in Russian], Moscow (1979).
30. A. A. Sandulyak, M. N. Polismakova, V. A. Ershova, et al., “Controlling ferro impurities in foods: drawbacks and main concepts for improving the normative-metrological base,” *Khronen Pererabotka Sel’khozsyrya*, No. 1, 60 – 66 (2011).
31. A. A. Sandulyak, M. N. Polismakova, D. V. Ershov, et al., “Functional extrapolation of the mass-production characteristics of magnetophoresis as a base for precision methods of controlling ferro particles,” *Izmeritel’naya Tekhnika*, No. 8, 57 – 60 (2010).
32. A. V. Sandulyak, M. N. Pugacheva, A. A. Sanduloyak, et al., *Method of Determining the Concentration of Magnetically Permeable Impurities in a Flowing Medium*, RF Patent No. 2409425 [in Russian], Moscow (2009).
33. A. A. Sandulyak, M. N. Polismakova, D. I. Svistunov, et al., *Apparatus for Determining the Content of Magnetically Permeable Impurities in Flowing Medium (Variants)*, RF Patent No. 93305 [in Russian], Moscow (2009).